

Diagnostics of Plasma Properties in Broad Line Region of AGNs

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Abstract. The Boltzmann-plot (BPT) method for laboratory plasma diagnostic was used for a quick estimate of physical conditions in the Broad Line Region (BLR) of 14 Active Galactic Nuclei (AGNs). For the BLR of nine AGNs, where PLTE exist, the estimated electron temperature are in the range $T \sim 130000\text{K} - 37000\text{K}$ are in good agreement with previous estimates. The estimated electron densities depend on the opacity of the emitting plasma in the BLR, and they are in range from 10^9cm^{-3} (for optically thick plasma) to 10^{14}cm^{-3} (for optically thin plasma). Although an alternative of PLTE in some AGNs may be very high intrinsic reddening effect, this method may be used for fast insight into physical processes in the BLR prior to applying more sophisticated physical models.

1. INTRODUCTION

The photoionization, recombination and collisions can be considered as relevant processes in Broad Line Region (BLR) of Active Galactic Nuclei (AGNs). At larger ionization parameters recombination is more important, but at the higher temperatures the collisional excitation also becomes important, as well as in the case of low ionization parameters. These two effects, as well as radiative-transfer effects in Balmer lines should be taken into account to explain the ratios of Hydrogen lines (Osterbrock 1989, Krolik 1999). Different physical conditions and processes can be assumed in order to use the emission lines for diagnostic of emission plasma (Osterbrock 1989, Griem 1997, Ferland et al. 1998). Although "in many aspects the BLRs are physically as closely related to stellar atmospheres as traditional nebula" (Osterbrock 1989), the plasma in the BLR probably does not come close to being in complete Local Thermodynamical Equilibrium (LTE). However, there may still be the Partial Local Thermodynamical Equilibrium (PLTE) in the sense that populations of sufficiently highly excited levels are related to the next ion's ground state population by Saha-Boltzmann relations (van der Mullen et al. 1994), or to the total population in all fine-structure levels of the ground-state configuration (see e.g. Griem 1997). The PLTE for different types of plasma: ionizing, recombining plasma and plasma in ionization balance were discussed in Fujimoto & McWhirter (1990). They found that the populations of higher-lying levels are well described by the Saha-Boltzmann equation. Recently, Popović et al. (2002) found that the Balmer lines of NGC 3516 indicate that the Balmer emitting line region may be in the PLTE.

Here we present a part of the results that will be given in more details in Popović (2003) concerning the test of the PLTE existence in BLR of AGNs using the Boltzmann-plot (BPT) of Balmer lines. We discuss the possibility of estimation of the relevant physical processes and plasma parameters in BLRs using this method.

2. THEORETICAL REMARKS

If the plasma is in PLTE, the population of the parent energy states adhere to a Boltzmann distribution uniquely characterized by their excitation temperature (T_e), and this temperature may be obtained from a Boltzmann-plot when the transitions within the same spectral series are considered (for more details see Konjević 1999, Popović 2003)

$$\log(I_n) = \log \frac{I_{ul} \cdot \lambda}{g_u A_{ul}} = B - A E_u, \quad (1)$$

where I_{lu} is relative intensity of transition from upper to lower level ($u \rightarrow l$), B and A are constants, where A indicates temperature and we will call it the temperature parameter.

If we can approximate the $\log(I_n)$ as a linear decreasing function of E_u then: a) it indicates that PLTE may exist at least to some extent in the BLR; b) if PLTE is present, the population adhering to a Boltzmann distribution is uniquely characterized by its excitation temperature. Then we can estimate the electron temperature from Eq. (1), $T_e = 1/(kA)$, where $k = 8.6171 \cdot 10^{-5} \text{ eV/K}$ is the Boltzmann constant; c) if PLTE is present we can roughly estimate the minimal electron density in BLR. Here, we should mention that "Case B" recombination of Balmer lines can bring the $\log(I_n)$ vs E_u as linear decreasing function (Osterbrock 1989). But, regarding the physical conditions (electron densities and temperatures) in BLRs in this case the constant A is too small ($A < 0.2$) and the Boltzmann-plot cannot be applied for diagnostics of electron temperature even if PLTE exists (see discussion in Popović 2003). Moreover, in this case Boltzmann-plot method can be used as an indicator of "Case B" recombination in BLR of some AGNs.

3. OBSERVATIONS AND DATA REDUCTION

In order to test the existence of PLTE in BLR, we use HST observations obtained with the Space Telescope Imaging Spectrograph (STIS) and Faint Object Spectrograph (FOS), covering the wavelength ranges 2900-5700 Å and 6295-6867 Å (rest wavelength). From the very large data base of AGN spectra at HST archive we selected the objects using following selection criteria: a) the observation covered the Balmer series line wavelength region; b) the observations were performed on the same day; c) all the lines from Balmer series can be recognized and all have relatively well defined shapes; d) we considered only low red-shifted objects.

To perform a test we subtracted the narrow and satellite lines from Balmer lines. To estimate the contribution of these lines we used a multi-Gaussian analysis (e.g. see Popović et al. 2001, 2002). We fit each line with a sum of Gaussian components using a χ^2 minimalization routine.

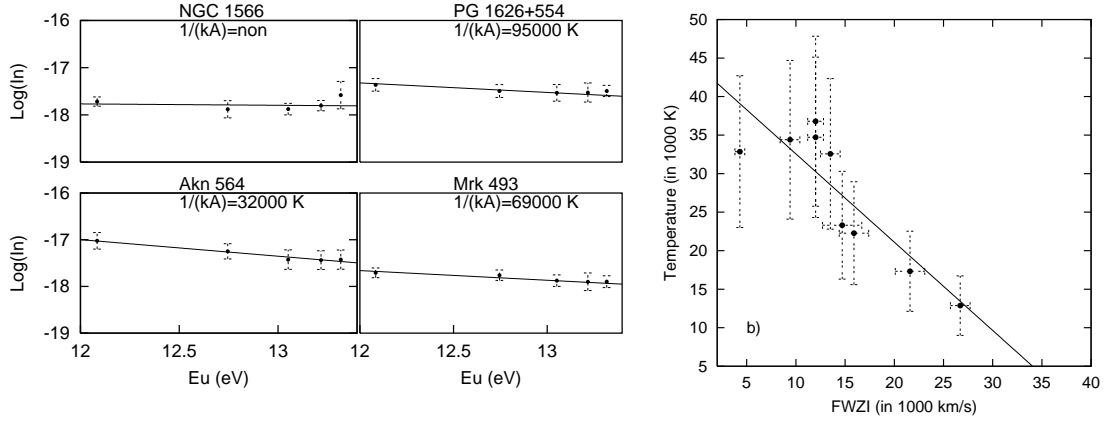


FIGURE 1. *Left:* The Boltzmann-plot for the Balmer lines of four AGNs from selected sample (NGC 2566 - BPT does not exist; PG 1626+554 and Mrk 493 BPT exists and indicates Case B recombination; Akn 564 - BPT indicates PLTE). The corresponding temperature, or $1/(kA)$, is given at the top of each panel. *Right:* Measured electron temperature as a function FWZI for the AGNs where BPT indicates presence of PLTE.

On the other hand, the reddening effect can influence the Balmer lines ratio (see e.g. Crenshaw et al. 2001, 2002, and references therein) and consequently on temperature parameter obtained by Boltzmann-plot. Here the Galactic reddening was taken into account using the data from NASA's Extragalactic Database (NED). In order to test the total (Galactic + intrinsic) reddening influence we have considered the case of Akn 564, where the reddening data are given by Crenshaw et al. (2002). We estimated that the reddening effect can contribute to the Boltzmann-plot slope around of 30%-40% (in the case of Akn 564 around of 35%, $(kA)/(kA)_{redd.} = 1.35$), but this effect cannot qualitatively disturb the straight line as a function in Boltzmann-plot. The reddening effect will always cause that temperatures measured by this method will give smaller values if this effect is not taken into account. In the rest of our sample we did not consider the intrinsic reddening effect.

4. RESULTS AND DISCUSSION

The more detailed discussion of the obtained results is given in Popović (2003), here we will give the basic conclusion.

From the test we found:

1) that from the 14 selected AGNs, in 9 AGNs Boltzmann-plot indicates the existence of PLTE in BLR, while in the case of 4 of them the Boltzmann-plot indicates "Case B" recombination in BLR. In remaining 1 AGN the Boltzmann-plot cannot be applied (see Fig. 1, left).

2) The estimated BLR electron temperatures using Boltzmann-plot where PLTE exists are in a range $(1.3 - 3.7) \cdot 10^4 \text{ K}$ (within 30% accuracy). They are in a good agreement with the previous estimations.

The electron densities in BLR have been considered for optically thin and optically thick plasma and we found that

i) For optically thin plasma, the electron density in the case of PLTE, at least in some parts of BLR, should be higher than conventionally accepted for BLR (order of 10^{14}cm^{-3}).

ii) For optically thick plasma, the electron density in the case of PLTE is in agreement with the conventionally accepted for BLR ($\sim 10^9\text{cm}^{-3}$).

On the other hand, as one can see in Fig. 1 right, the electron temperatures estimated by using Boltzmann-plot tend to be velocity dependent as a linear decreasing function of random velocities measured at Full Width at Half Maximum (FWHM) as well as Full Width at Zero Intensity (FWZI).

The Boltzmann-plot method is very useful for probing of the physical properties of BLRs where PLTE exist. On the other side, although the alternative of PLTE indicated by the Boltzmann-plot method may be considered (e.g. Case B recombination + high intrinsic reddening effect), the method may be used for fast insight into physical processes in BLR of AGNs prior applying more sophisticated BLR physical models.

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